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Orientation Systems: First Things First

by

Robert H. Wright

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Prefatory Note

This paper is based on research performed by the Human Resources Research Organization's Division No. 6 (Aviation), Fort Rucker, Alabama, under Work Unit LOWENTRY, Methods for Improving Navigation Training for Low-Level Flight. Work Unit LOWENTRY, under Dr. Wright's direction as Work Unit Leader, was a series of studies concerned with improving techniques and training for Army low-level navigation. Military support for the research reported here was provided by the U.S. Army Aviation Human Research Unit and the U.S. Army Aviation Center.

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ORIENTATION SYSTEMS: FIRST THINGS FIRST

Robert H. Wright

In the geographic orientation business, because of neglect of our "homework" we have pursued development of sophisticated, automatic geographic orientation systems that are not practical for Army aviation. There has not been an acceptable descriptive analysis of the geographic orientation process; seldom has an available billion-element "computer" already interfaced with highly effective sensor systems, man, been considered in design of geographic orientation systems. Also, we have not really examined the environment and requirements of the potential buyer of the systems, Army aviation. In most businesses, I believe, heads would roll if management couldn't describe how their proposed process worked, if they ignored extensive resources for accomplishing the job and if they didn't even know the needs of a major potential consumer.

Before Army aviation can obtain an effective geographic orientation system, it appears that basic work must be accomplished in the areas of (a) description of the geographic orientation process, (b) consideration of the proper contribution of the crew, and (c) familiarization with the pertinent requirements of Army aviation. I would like to consider briefly each of these areas.

In essence, an effective geographic orientation system for Army aviation will require the system analysis and design approach to produce an effective *man-machine system*, and not just an elaborate automated machine that does not consider the *man* part of the system. An Army aviation geographic orientation system to be used on its smaller aircraft will be required to use crew members' capabilities to their full potential if it is to be practical. These capabilities represent the equivalent of a billion-part sensor-computer system with many of the functions necessary in a geographic orientation system. If this billion-part system were hardware, its capabilities would automatically form the primary basis for the approach to system design. In developing the most effective, lowest cost geographic orientation system for Army aviation, this asset should also form the primary basis for the approach to system design. However, can an honest claim be made that the primary design basis of any geographic orientation system has been a list of crew capabilities?

ANALYSIS METHODOLOGY

I am not aware of a single example that I would consider a satisfactory analysis of the geographic orientation process in aviation, yet such an analysis seems fundamental to the design of effective man-machine systems. My attempts to use available analytic techniques have

been frustrating in their failure to even approach a full description of the process. Figure 1 illustrates an analysis technique that has recently been developed with the hope of providing better results for analysis of navigation and other higher order functions such as tactics. It is based primarily on definition of hierarchal levels of system functions—mission or goal level, tactics/strategy level, status level, state level, and action level. Each level is divided into elements concerned with planning (obtain relevant information, evaluate and integrate, select courses of action, and program) and with plan execution (program, action, indications, and comparison).

The role of the crew seems to be much clearer with this analysis approach, and the tendency to over-automate is minimized. The higher level functions that the crew has to perform are found at the upper levels, and those functions that it is feasible to consider automating are found at the lower levels. Of major concern for navigational systems are the elements concerned with planning functions (shown at the left of the figure) which must be largely crew performed, and the comparison between indications and programs during execution which, again, must be performed by the crew.

If we are to consider only "all-or-nothing" types of geographic orientation systems that are so expensive they can be afforded for only a few Army aircraft, this thorough system design analysis can be ignored. If a geographic orientation system suitable for all of Army aviation is to be developed, however, then an extensive system analysis that recognizes the crew involvement in the hierarchal structure of the process would seem necessary. In designing systems compatible with a low-level, darkness/limited visibility operational environment, this approach would seem doubly necessary.

Applying this type of analysis to geographic orientation requirements throughout Army aviation missions, a large number of conclusions evolve; I would like to point out some of them.

On a general basis several factors should be noted. One is that without a map display, the basic comparison test between navigational indications and program cannot take place directly. Procedures, or a combination of procedures and less sophisticated job aids, must be performed at lower levels in order to accomplish this test. A second factor is that the left side of the diagram is the primary concern of geographic orientation whenever the right side comparison test is not positive. The obtaining and storage of relevant information in a manner compatible with evaluation and integration requirements for planning and plans revision should be a matter of major concern—this has been largely ignored in the past. A third general factor is that geographic orientation, primarily a third level "status" concept, falling between the higher level tactics and lower level states and actions, is a concept that must be applied in planning to translate tactics plans into plans for system states and actions.

Our past Visual Flight Rules (VFR) direct perceptual world has led us to take this translation for granted, but in the Army's future operational environments the specifics of the translation may require

Hierarchal Loop Analysis Schematic

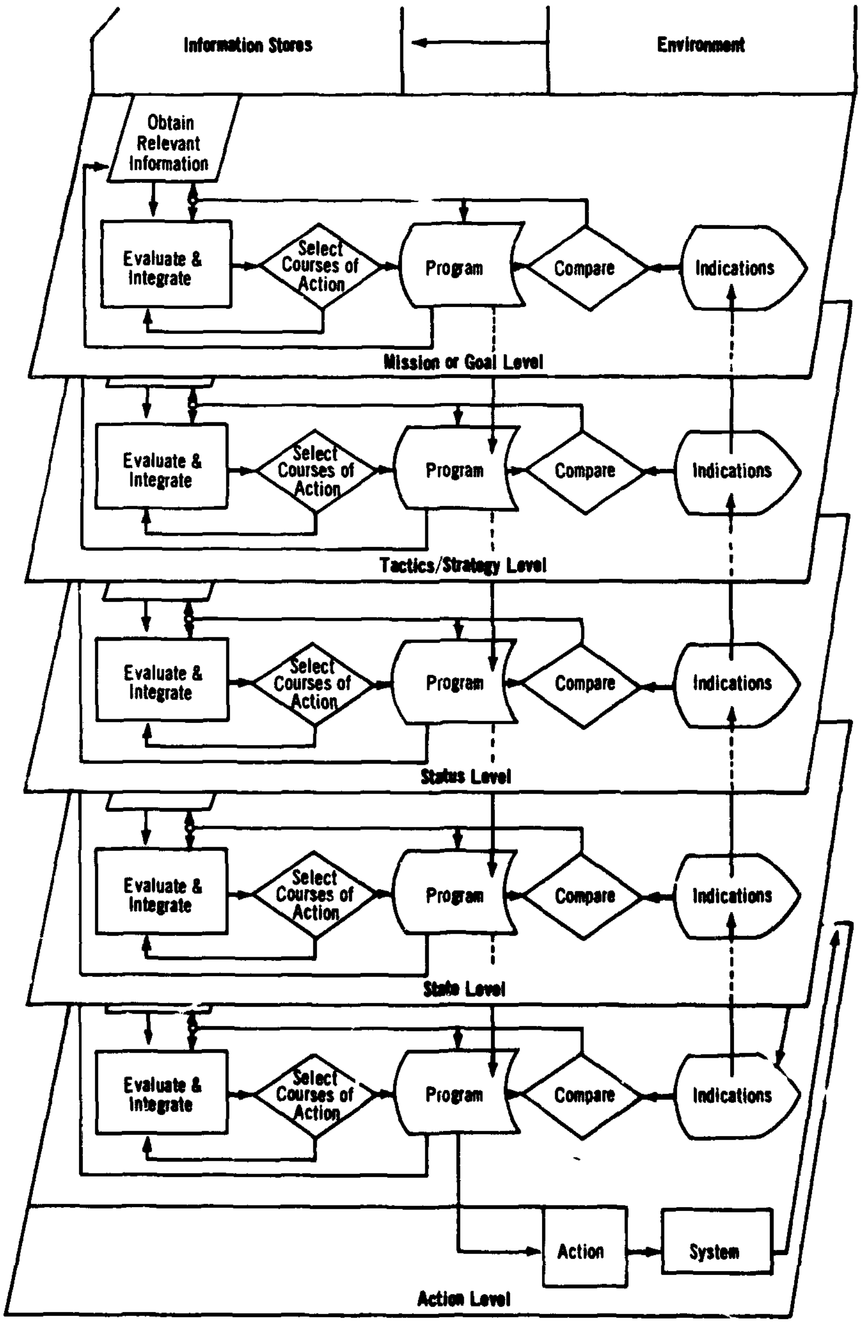

Figure 1

considerable attention in system design. Let me mention several more specific factors that should receive attention in the design of geographic orientation systems for Army aviation.

CLOSE-IN GEOGRAPHIC ORIENTATION

Geographic orientation in air operations, according to Webster's dictionary, should be "a determination or sense of the position of one's aircraft in relation to its geographic environment; in particular, in relation to the earth's surface and its natural and man-made features, in relation to objects and persons on that surface, and in relation to defined geographic reference coordinate systems." Lack of geographic orientation thus defined appears to be a causal factor in about 80% of Army aircraft accidents.[1] Yes, that was 80%! Although some involve lack of spatial or navigational orientation, most of these accidents involve a lack of orientation to the immediate local geographic environment. We run into the ground, other aircraft, trees, buildings, ground vehicles, and people.

In view of the possibility that a large number of the Army's aircraft losses and damage may be caused by a lack of orientation to the immediate geographic environment, I would like to discuss this major Army geographic orientation requirement and to show that it has significant interaction with what seems to be the major theme of this symposium, navigational orientation. My point is that for the Army pilot, geographic orientation problems may by only starting when he locates his destination. This appears to be particularly relevant for desired future Army capabilities of operating at low level in darkness and limited visibility.

Navigation systems and radars can bring a pilot only "so close"; in that final mission payoff region, a geographically oriented pilot must take over and dodge the trees and stumps to set the chopper down, to hover over that man or load, or to shoot at a target. Without pilot orientation to the immediate local geographic environment at his destination, the Army aviation mission cannot be accomplished. The Apollo moon landing situation happens thousands of times a day in Army aviation, and when under enemy fire, every second is critical. There are some who claim that automation of control is the solution to problems of this critical helicopter flight regime, but I contend that the answer is in pilot geographic orientation. An oriented pilot won't land on stumps, won't fly backward into a tree or sideward into another chopper, whereas an automatic control system won't really make a difference in avoiding these accidents. I doubt that any of you close your eyes and let your wife *tell* you how to maneuver your car into a parking place, yet this is basically how we maneuver our helicopters in load and rescue work.

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[1]Personal communication, LTC Robert W. Bailey, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, October 1969.

Due to lack of orientation, frequently five minutes are used to accomplish what is basically a ten-second load operation. Direct visual geographic orientation to hook-object relationships seems as obvious for controlling a helicopter as looking when parking a car, yet a pilot currently hovers over a load looking forward just as if he were still flying a fixed wing aircraft. It takes a very exotic inertial or doppler navigation system to maintain the precision hover required for load work with a stationary object, and these systems still can't handle the moving object situation and cable oscillation. For all situations, however, the human eye through almost any sort of visual link can easily determine hook-object relative orientations and relative rates with sufficient precision for rapid load work at a hover.

Satisfactory geographic orientation in the area under and directly adjacent to the helicopter is essential to satisfactory and safe Army mission performance, but is not currently available. Orientation in these areas under conditions of darkness is a particularly critical requirement if Army aviation is to be able to operate in darkness without resorting to artificial illumination. The aerospace industry's past orientation to forward-oriented, fixed-wing instrumentation for large airfields with mile-long runways cannot cope with the Army helicopter pilot's omnidirectional orientation requirement at "hole in the trees" type landing sites, and some instrumentation concepts directly related to these helicopter pilot information requirements appear necessary.

The Army aviator's primary geographic orientation requirements, therefore, from the standpoints of both safety and mission accomplishment, appear to be (a) orientation when hovering to terrain and features *under* and within about a 100-meter radius *all around* the helicopter, changing to a forward orientation as cruising speed is approached, and (b) spatial or attitude orientation. A corollary requirement is recognition of the close coupling at hover between attitude and terrain orientation. The Army pilot's direct vision is currently the only way these primary mission payoff geographic orientation requirements are met, but some indirect vision substitute is essential for an effective capability for operating in darkness, and for *safely* operating in daylight conditions.

LOCAL AREA GEOGRAPHIC ORIENTATION

While the close-in geographic orientation discussed is the most critical since it is essential to the final step in accomplishing Army aviation's primary mission of movement of troops, equipment, and supplies, geographic orientation to the local area from 100 meters to about 5,000 meters is also a critical Army aviation requirement. For some missions, such as those performed by gunships and observation aircraft, the primary geographic orientation requirement is the local area type. It is essential to the low-level operational effectiveness of gunship and observation aircraft, and probably the primary factor in the degree of success in employing these aircraft at higher altitudes, particularly in darkness. This geographic orientation requirement has been almost completely ignored in past and current Army systems and equipment, since the pilot's sense of local geographic orientation was

usually sufficient to do the job. In attempting unprogramed maneuvering in a local area at low level, or looking out into inky blackness with only a tiny portion of the area in view on a low-light level TV, however, a pilot is at or beyond his limits of maintaining local geographic orientation.

Attempting to use currently available forward oriented night vision systems illustrates the local geographic orientation problem. After 20 minutes of flying a search pattern on instruments, the observer says, "I think I have something." But, before the pilot can look at it, the observer comes back with, "We have passed it," as the scan limit stops are hit, since the systems are forward oriented. The pilot goes back to his instruments and tries to execute a standard procedural turn that will bring them back over the suspect object. Notice I said "tries," for the pilot has no way of knowing the location of that suspect object or a path that will go over it, except from his own internal sense of orientation obtained from viewing his standard Instrument Flight Rules (IFR) instruments. The same situation exists when a low-level aircraft receives enemy fire, evades it by flying behind masking terrain, and then would like to return and to engage the enemy from a favorable low-level attack position. A precise local geographic orientation to the target and its surrounding terrain must be maintained without its actually being in view. Again the pilot's own internal sense is the only source of geographic orientation for accomplishing this requirement.

The coordination of local geographic orientation within and between aircraft crews is essential to the effective employment of gunship fire teams, observation aircraft, and the hunter-killer concept of pairing of observation and gunship aircraft. In darkness, coordination of local geographic orientation is probably the most critical factor in the success or failure of these missions, yet no provisions for this orientation exist except for the eyeballs and brain of the crew. With flare illumination the daylight orientation situation is approached, but with night vision equipment, a formidable task exists of integrating visual and instrument cues in order to maintain local geographic orientation.

Where enemy fire is coming from, where our sensors are pointed, where our weapons are firing, where other mission team aircraft are with respect to our aircraft, where their sensors and weapons are aimed, location of our friendly troops and their fields and types of fire, location of friendly artillery and their trajectory pattern, and location of enemy troops and their antiaircraft weapons, all have to be integrated into a coherent local geographic orientation picture and maintained as the aircraft is maneuvered around the local area.

Specific provisions for giving this local geographic orientation appear to be essential for Army achievement of the operational potential that is inherent in night vision technology. Narrow telescopic lenses, although necessary for obtaining maximum target detection *ranges*, significantly reduce geographic orientation along with the *probability* of target detection. In many ways there appears to be a high correlation between this *probability* of target detection and local

area geographic orientation. If the probability of detecting a target is low, it usually follows that the probability of detecting orientation features will also be low.

A specific example illustrates the basis for concern in regard to local geographic orientation. Assume one aircraft has located a target with a night vision device and is illuminating it with a laser or Instrument Reading (IR) spotlight to transfer it to another aircraft. With a normal field of view lens of 20 by 25°, there is only about one chance in 50 that this bright spot would be in our field of view, on the basis of the ratio of the scene area to the potential scene area of the entire lower hemisphere. About two and one-half minutes' search at three seconds per scene would be required for full coverage of this spherical angle with a normal lens. With a telephoto lens the search time would increase in inverse proportion to the square of the angle of view. Although various operational procedures would reduce the actual search times, these basic geometric considerations indicate that a wide angle sensor is needed if the required close-to-instantaneous transfer is to be expected.

When at low level, the majority of the most useful information for geographic orientation exists in the right and left quadrants at the moment of crossing linear features such as roads and streams. In order to obtain good information for geographic orientation at night at low level, a viewing device capable of looking to the right and left, as well as down, will therefore be necessary.

For operationally effective local area geographic orientation, especially during periods of darkness, these considerations indicate that wide angle real time sensors are required to obtain information. Further considerations indicate these sources of information should be closely integrated with a local area geographic orientation display system that is capable of timely integration of this information in an operationally useful format. Evidence is starting to accumulate rapidly indicating that specific provisions for this local and close-in geographic orientation will be an essential requirement for effective operational employment of night vision types of display systems.

Figure 2 illustrates an approach for providing these close-in and local geographic orientation requirements in a format integrated with conventional navigational orientation displays. A full 360° horizon is available that conforms with the compass rose of a Radio Magnetic Indicator (RMI), yet an artillery piece under the helicopter and the cable and hook to be attached to it are also in view, along with the helicopter skids and nearby telephone poles. Although unusual in appearance from the standpoint of our conventional fixed wing instrumentation orientation, the entire approach should be well within current technology, including the circular overlay figure designed to provide all basic flight control information in a natural manner. It is based on a downward pointed panoramic lens image format, which detailed analysis indicates has a number of advantages for providing geographic orientation information, including the elimination of many accidents involving backing into or moving sideward into objects when at a hover. A specific question that appears to merit consideration is a similar presentation

Downward Pointed Panoramic Close-In and Local Geographic Orientation Sensor Concept Sketch

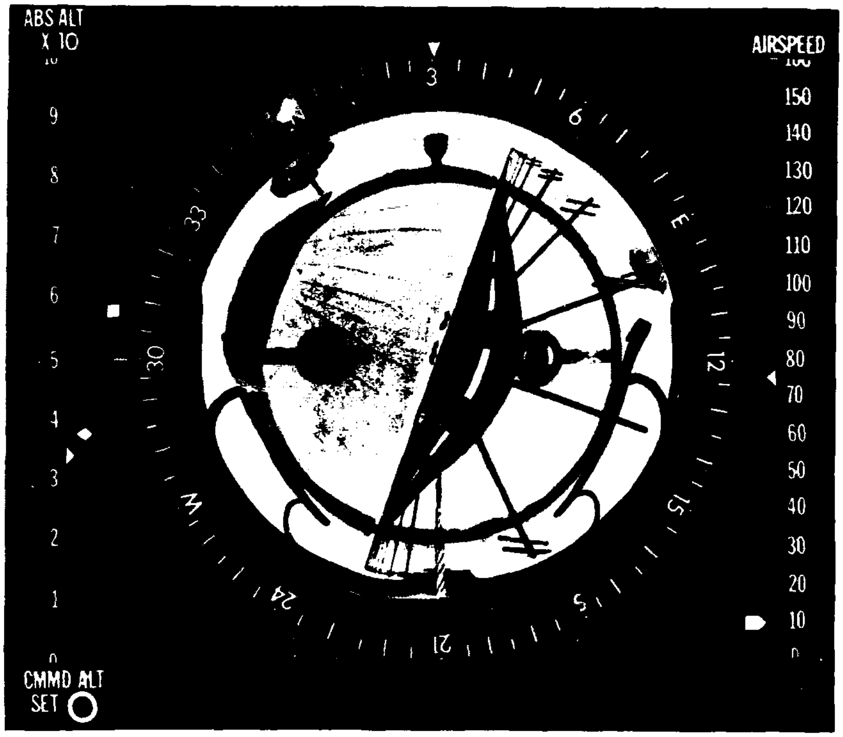

Figure 2

format for a map display. Such a format is potentially capable of providing high detail regarding present position map details while retaining useful azimuth and elevation angle orientation to features a considerable distance away.

NAVIGATIONAL SYSTEMS

Analysis of navigational systems, as man-machine systems rather than simply as equipment, indicates that arrival at a destination is achieved either by inherent accuracy in the navigational equipment, or by crew member refinement and interpretation of information that is not inherently capable of providing destination arrival. The crew member's ability to use a map should be the key to the success or failure of his participation in the navigational process. Unfortunately, in Army aviation we find that the source of failure in navigation is usually a data processing error, or the excessive attention that must be devoted to this processing. A human pilot is only about 90% accurate as a data processor under favorable

circumstances, and can produce results only on an intermittent basis. The simplest of automated E6B's, on the other hand, are around 99% accurate and produce continuous results, and the errors that do result are small ones rather than giant-sized, as humans are prone to produce.

Given this automated E6B in proper design, the Army aviator's geographic orientation is practically assured in *all* Army aircraft. Without it, gross inconsistencies in geographic orientation will exist across the family of Army aircraft, that will in turn have major consequences on the operational effectiveness of Army aviation as a system. The automated E6B, therefore, is considered the essential element in attainment of acceptable Army aviation system-wide geographic orientation. If crew member data processing errors and attention are eliminated, their pattern matching abilities should be able to provide effective performance no matter what the sensor accuracy. A map display should, of course, help to provide acceptable performance, but acceptable operational performance should usually exist with only continuous digital or graphic readouts used in conjunction with hand-held maps.

Preoccupation with sensor technology, rather than with effectiveness of the total man-machine geographic orientation system, has precluded availability to Army aviation of highly satisfactory geographic orientation that has been technically feasible for 20 years. It is hoped that a similar preoccupation with map displays will not further delay availability of this capability. The only logical way to approach design of a geographic orientation system for Army aviation is to examine the "trade-off" between geographic orientation performance per dollar invested in equipment. Available evidence leads to an estimate that about 85 to 90% of the performance possible from the most costly system should be provided by only the automated E6B, at around 5 to 10% of the cost. By adding a graphic display highly compatible with maps, around 90 to 95% of potential performance should result, and with a good map display, about 95 to 98% of potential performance should exist. Although these "ballpark" estimates may be in error, the available evidence certainly indicates that most of the Army user's required performance should be obtainable at a small fraction of the cost of sophisticated navigational systems, simply by letting the man participate in the man-machine system.

To those who believe that the exceptional IFR situation, rather than the average, should be the basis for system design, I agree that such a weighting is desirable. However, having the Army crew just sit and do nothing in IFR conditions is an extremely unlikely situation, unless system design precludes any positive contribution from them. The crew's tool-using abilities should be an integral consideration, and I would like to point out one example of how crew abilities could contribute to navigational system accuracies in IFR. Although a combined CRT-map display would be ideal, let me assume a more austere system of just digital readout and hand-held map.

Considering that electrical signals from absolute and barometric altimeters should soon be available, this information will be used to update the navigational system using terrain relief correlation.

Although the typical engineer's reaction is that this process is a monumental Research and Development and computer requirement, consideration of the crew member's pattern-matching abilities indicates that it should be a simple task for that multi-billion element computer—his brain. If altimeter signals are combined and gated to read out present position coordinates at low points after highs of certain difference values, the crew can note and plot these coordinate values on grid coordinate transparent plotters as shown in Figure 3. After two or three of these points are plotted, matching these points for best fit with terrain lows on the map, or stream lines, will provide an accurate update through noting and inserting the differences in grid coordinate alignment. Terrain elevation at these points would provide a desirable redundant check of this process. By providing an event marker producing a similar position readout that a crew member could actuate when crossing a road or any other useful line feature, a similar update process could be used with other features. Although computerized pattern matching is a big task for current technology, for the human crewman it is a simple few-second process, as shown in

Map and Transparent Grid Coordinate Plotter

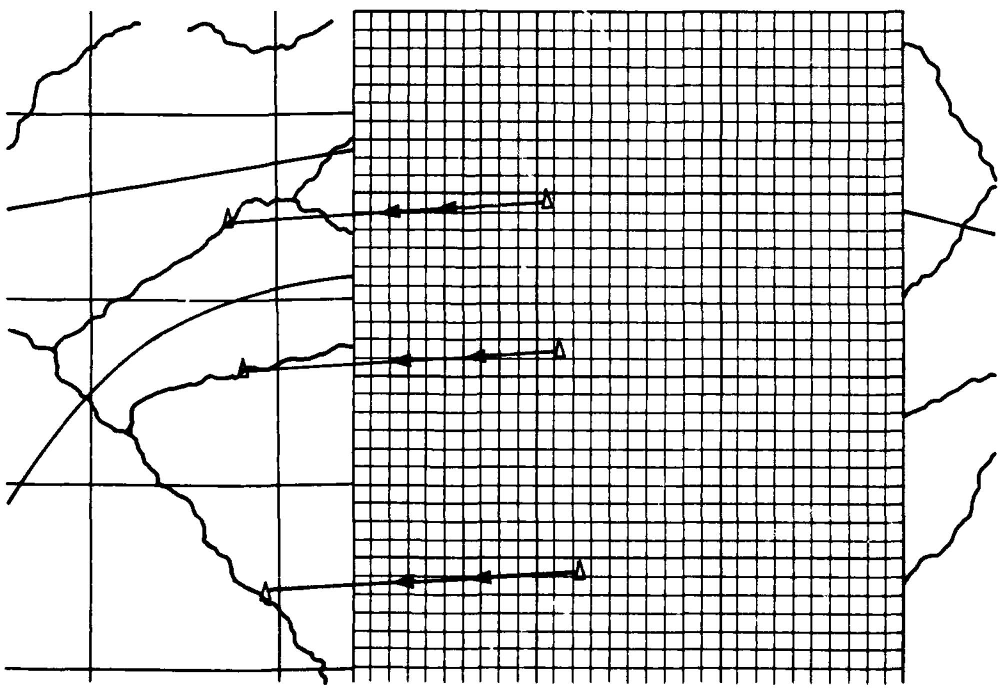

Figure 3

Figure 3, of sliding one pattern over the other until the best match is obtained. (In presentation, plotter overlay is moved into "best fit" position.)

I am not at all certain that such a capability would be a desirable requirement for a geographic orientation system. When its costs are considered against the costs and field reliabilities of sophisticated gyro sensors or alternative high accuracy sensors, however, it would seem to merit consideration in the system definition process. The important point, however, does not concern the merits of this particular technique, but the need to include explicit consideration of the crew member and his potential capabilities and limitations in the system design process.

SUMMARY

The geographic orientation requirement for the Army's lighter aircraft and for Army aviation as a system, is a system analysis and system design problem that appears to have so far defied solution. The factors considered in this paper have been intended to indicate that the Army's geographic orientation requirement is not readily amenable to solution by a simple "more sophisticated machine" systems approach. Instead, full consideration of the potential of the man part of the man-machine system and the deliberate inclusion of man in the design enabling him to contribute his full potential as a functional part of the system, appears essential for an economically feasible and operationally effective geographic orientation system. In addition, the Army aviation operational environment, with all of its complex interacting coordination requirements, also needs to be given full consideration.

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13. ABSTRACT

The geographic orientation requirement for the Army's lighter aircraft, and for Army aviation as a system, is a system-analysis and system-design problem that appears to have defied solution. The factors considered in this paper indicate that the requirement is not filled by a simple "more sophisticated machine" systems approach. Instead, the *man* part of the man-machine system needs to be deliberately "designed in" to contribute his full potential as a functional part of the system. Also, the Army aviation operational environment, with all of its complex interacting coordination requirements, needs to be considered, for an affordable and operationally effective geographic orientation system.

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